DIRC-based PID for the EIC – Progress Report for Year 1

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Generic Detector R&D for an Electron Ion Collider

Advisory Committee Meeting, BNL, December 13, 2012

Outline

1. Introduction

- DIRC principle
- Cherenkov angle resolution

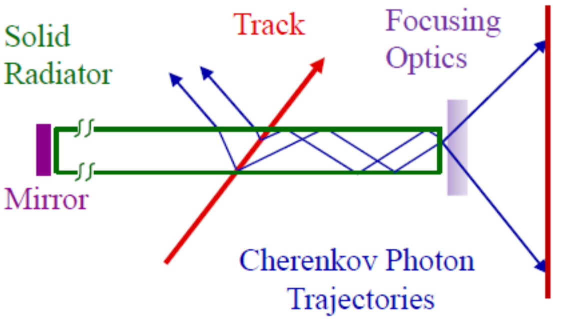
2. Summary of Year 1

- Simulations
- Hardware
- Travel
- What was achieved?

3. Outlook for Year 2

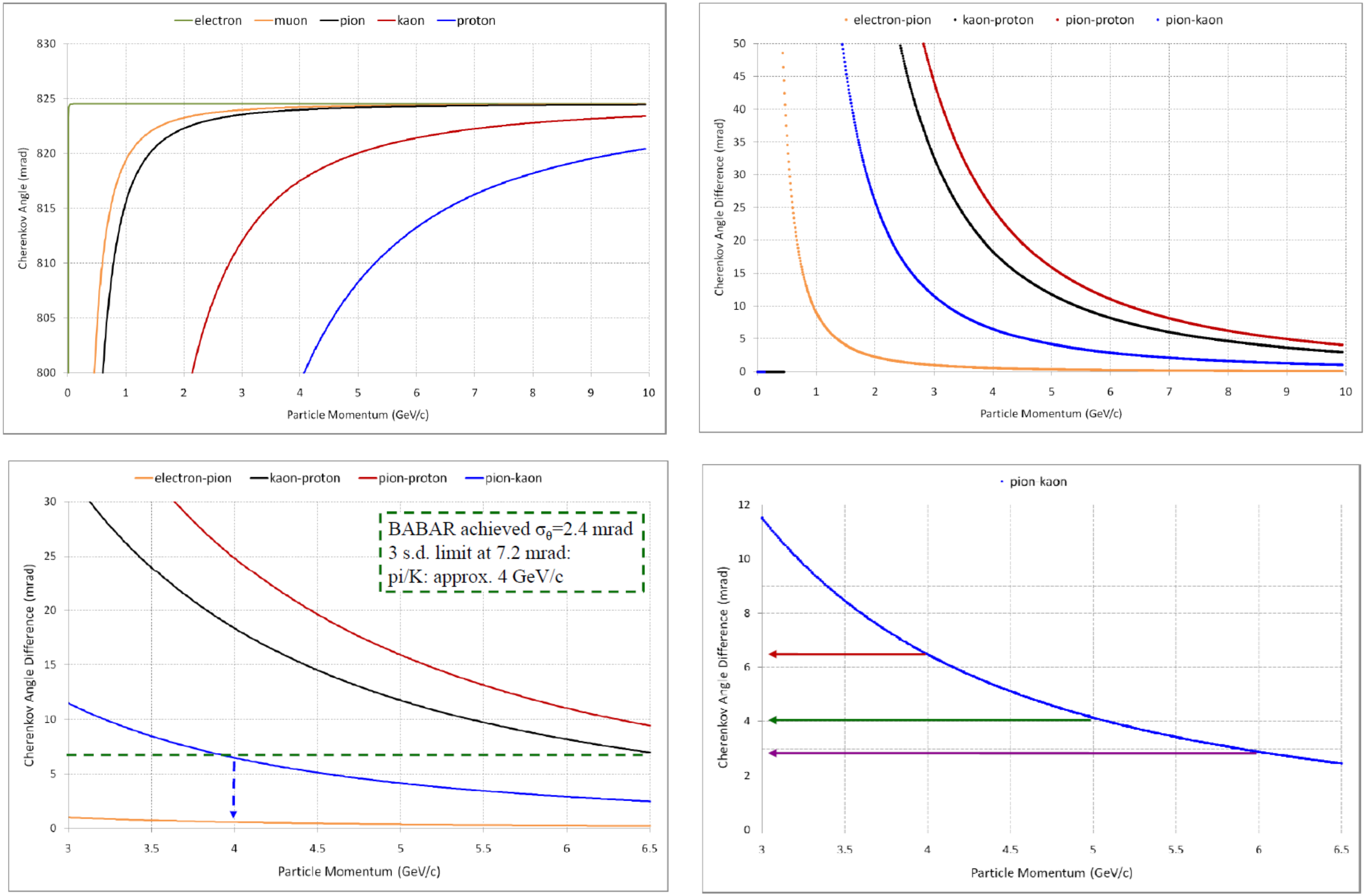
- High-magnetic field sensor testing facility at JLab

DIRC principle



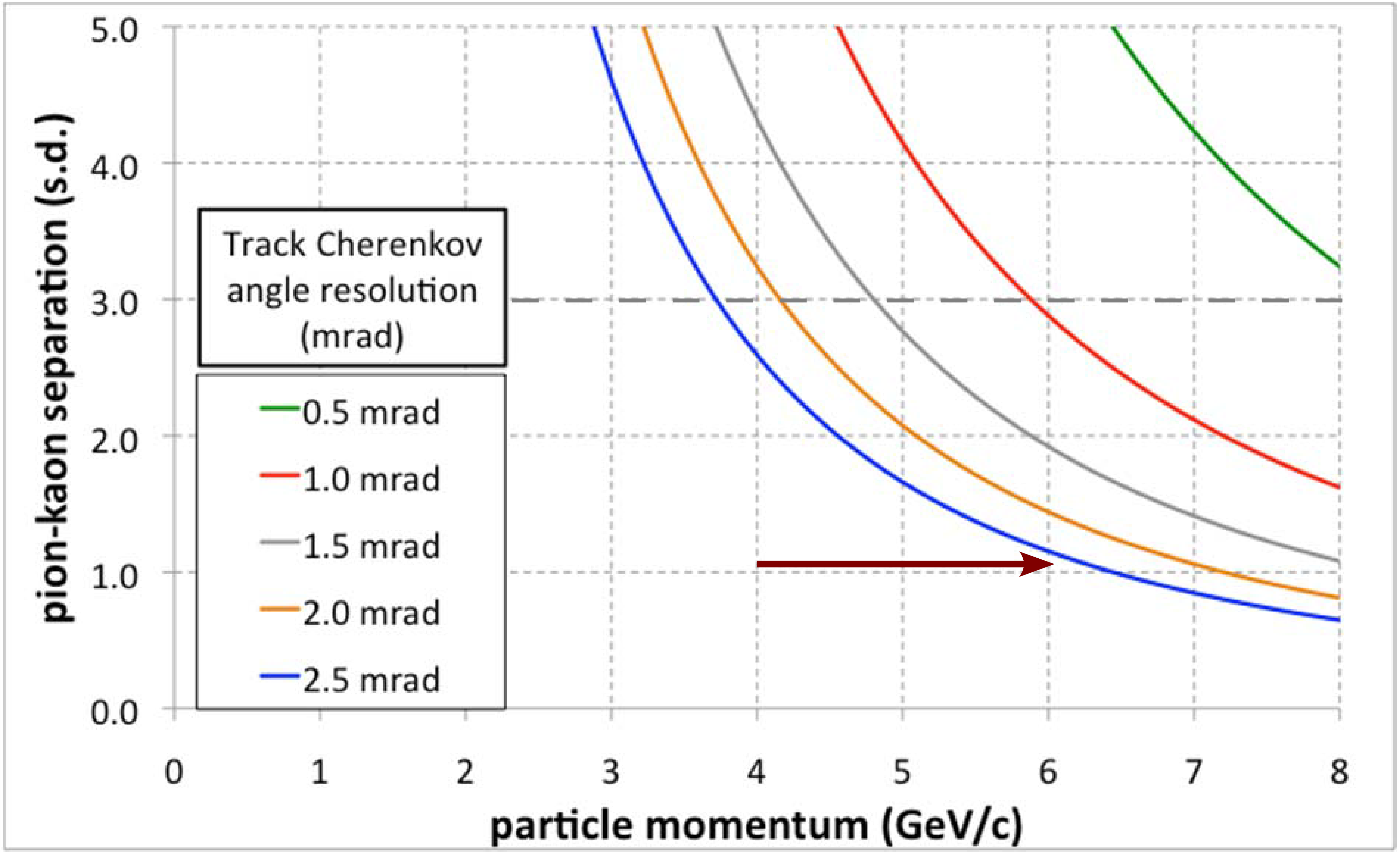
- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)_c$
- For n > √2 some photons are always totally internally reflected for β ≈ 1 tracks.
- Radiator and light guide: bar made from Synthetic Fused Silica
- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)
- Photons exit radiator into expansion region,
  detected on photon detector array.
  (pinhole imaging/camera obscura or focusing optics)
- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, φ_c, $t_{propagation}$ of each photon.

Momentum coverage and θ_c resolution



- Extending π/K separation from 4 to 6 GeV/c requires $\sigma_\theta \sim 1$ mrad (vs 2.4 in BaBar – a 58% reduction).

PID as a function of θ_c resolution



Improving the θ_c resolution

$$\sigma_{\theta_c}^{track} = \frac{\sigma_{\theta_c}^{photon}}{\sqrt{N_{p.e.}}} \otimes \sigma^{correlated}$$

Correlated term:
tracking detectors, multiple scattering, etc

$$\sigma_{\theta_c}^{photon} = \sqrt{\sigma_{bar-size}^2 + \sigma_{pixel-size}^2 + \sigma_{chromatic}^2 + \sigma_{bar-imperfection}^2}$$

BABAR-DIRC Cherenkov angle resolution: 9.6 mrad per photon → 2.4 mrad per track

Limited in BABAR by:			Could be improved via:
· size of bar image	~4.1 mrad	→	· focusing optics
· size of PMT pixel	~5.5 mrad	→	· smaller pixel size
· chromaticity ($n=n(\lambda)$)	~5.4 mrad	→	· better time resolution
	9.6 mrad	→	4-5 mrad (?) per photon
· number of photons	15-50	→	· photocathode/SiPM

topics for R&D proposal

- DIRC bar thickness can in principle also be increased beyond the 17 mm (19% r.l.) used in Babar
- Excellent 3D imaging (2 spatial + time) essential for pushing performance beyond state-of-the-art

R&D goals

1. Demonstrate feasibility of using a DIRC in hermetic EIC detector

- Compact readout “camera” (expansion volume + sensors)
- Operation in high magnetic fields (up to 2-4 T)

2. Investigate possibility of pushing state-of-the-art performance

- Extend 3σ π/K separation beyond 4 GeV/c, maybe as high as 6 GeV/c
  - also improve e/π and K/p separation

3. Study integration of the DIRC with other detector systems

- Supplementary gas Cherenkov?
- Integration with solenoid, tracking, calorimeter, etc
- Accelerator backgrounds (in collaboration with SLAC)

Primary responsibilities

1. Simulations of DIRC performance and design of EV prototype

- Old Dominon University

2. Integration with the EIC detector

- Catholic University of America

3. Prototyping and hardware test (except high magnetic fields)

- GSI Helmholtzzentrum für Schwerionenforschung

4. Sensor test in high magnetic fields

- University of South Carolina and Jefferson Lab

***Note:* The proposal is a collaborative effort and most institutions will contribute to more than one of the areas above regardless of their primary responsibility**

Design choices

1. Focusing

- Proximity focusing (BaBar)
- Mirror on the side opposite of readout (Belle)
- Mirror on the side of the readout (SuperB)
- Lenses (PANDA)

2. Expansion volume and sensors

- Inside detector volume
- Outside of endcap and iron

3. Radiator bars

- Boxes of narrow bars (BaBar)
- Plates = wide bars (Belle)

Design strategies

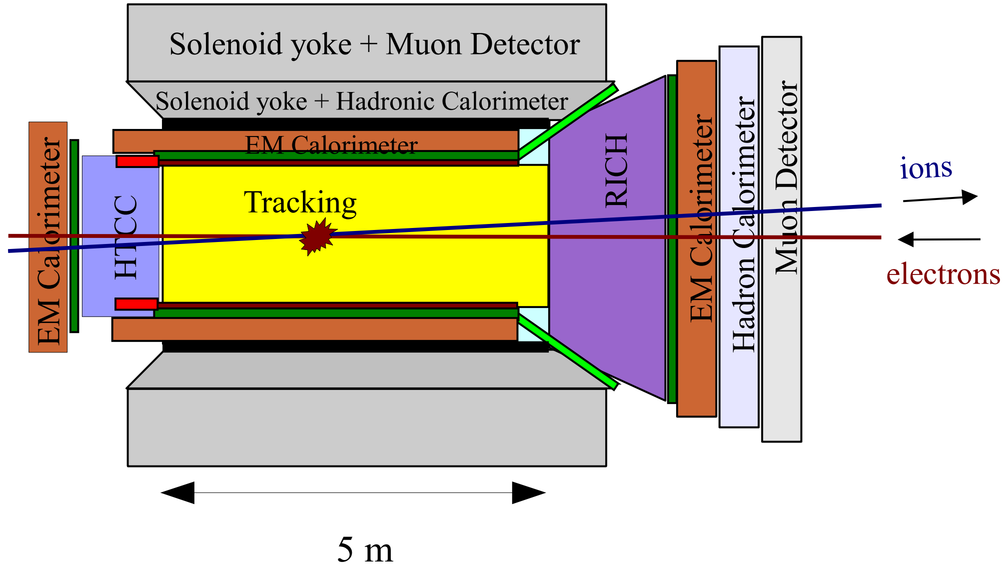
1. Expansion volume inside detector

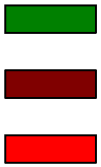
- Bars of moderate length (4-5 m) – can be narrow
  - Reconstruction well understood for narrow bars
  - Can handle high multiplicity events
- Compact expansion volume important – fused silica
  - Lens focusing primary choice – concept benefits from PANDA R&D
- Sensor challenges
  - High magnetic fields – low-noise SiPMs interesting (but single-photon detection required)
  - Radiation

2. Expansion volume outside detector endcap and iron

- Longer bars – plates preferable in order to reduce number of reflections
  - Lower tolerances and potentially lower cost (50-75%)
  - Requires new reconstruction methods – synergies with PANDA R&D
  - Segmentation requirements (number of plates) need to be studied
- Fewer constraints on EVsize and orientation – can be radially large
  - Mirror focusing natural choice (uniform angular performance) – similar to SuperB
- Sensors – easier access and moderate magnetic fields
  - MCP PMTs?
- Major impact on endcap detectors – needs to be studied!

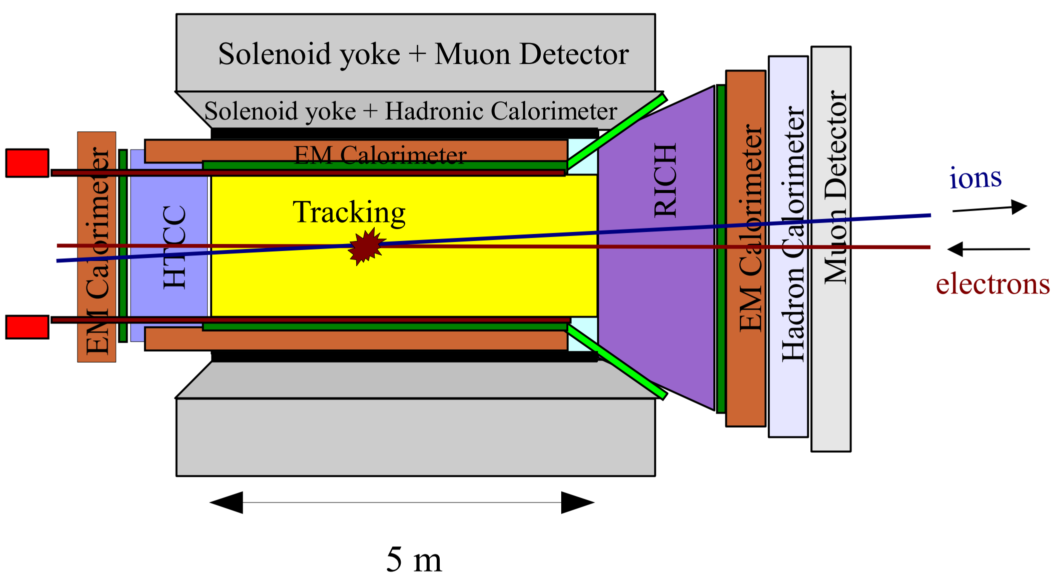
Possible layouts with internal and external EV





- TOF
- DIRC bar
- DIRC expansion volume

- A DIRC-only PID solution in the barrel could be adapted to placement of the EV inside or outside of the detector.



- The DIRC bars/plates would be quite long if the EV was outside.

- Impact of penetrating bars on endcap design?

R&D strategy – simulations and design

1. Proof of Concept (year 1)

- Configuration with lens focusing and EV inside detector
- New lenses with high index of refraction developed
- Reconstruction package developed (needed for figure of merit)
- Ray tracing (drcprop) simulations show 1 mrad resolution!
- Next: optimization and prototype design

2. Design optimiziation for EIC detector (year 2)

- Due to promising year 1 results, the focus has shifted towards simulating DIRC-only configurations without a supplementary threshold Cherenkov or barrel RICH
- Both internal (lens) and external (mirror) configurations will be investigated
- A mirror-based prototype will also be designed

3. Other configurations

- Bar with mirror on the opposite side of EV (a la Belle) has been studied in drcprop
  - Results were not promising and it has not been pursued further
- Bar with Babar geometry EV has been implemented in GEANT4
  - Intended as a benchmark for GEANT4 simulations

Event reconstruction I

Calculate unbiased likelihood for signals to originate from e/μ/π/K/p track or from background:

Likelihood: **Pdf(θ_c) x Pdf(Δt) x Pdf(N_γ)**

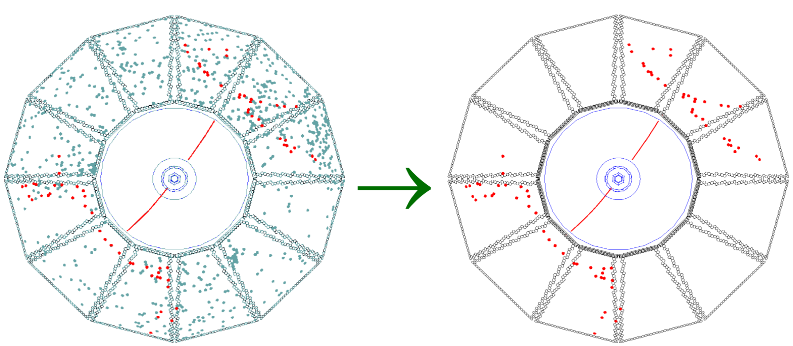
Pdf = Probability distribution function

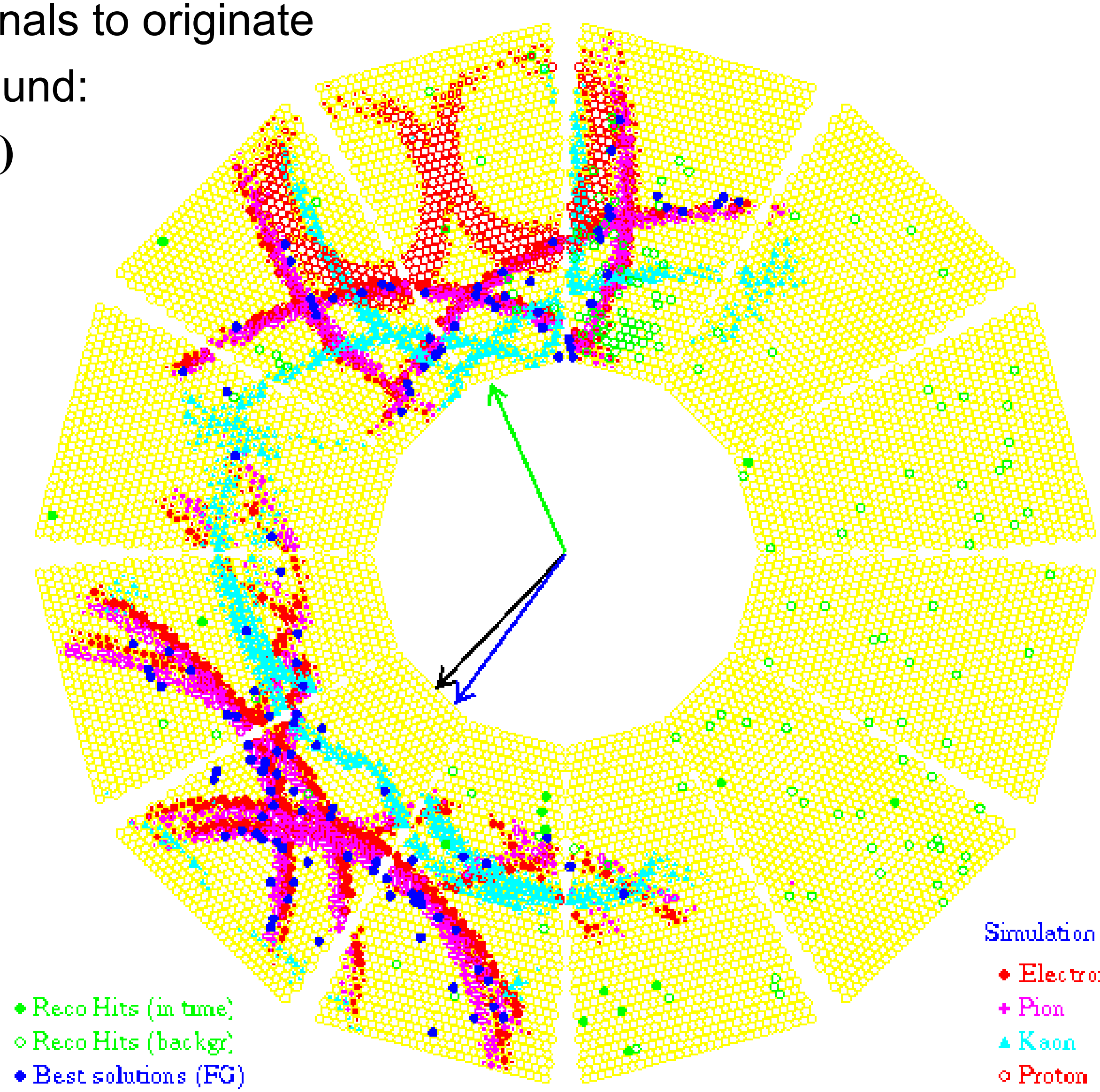
Example: comparison of real event to simulated response of BABAR DIRC to e/π/K/p.

Time resolution important for background suppression

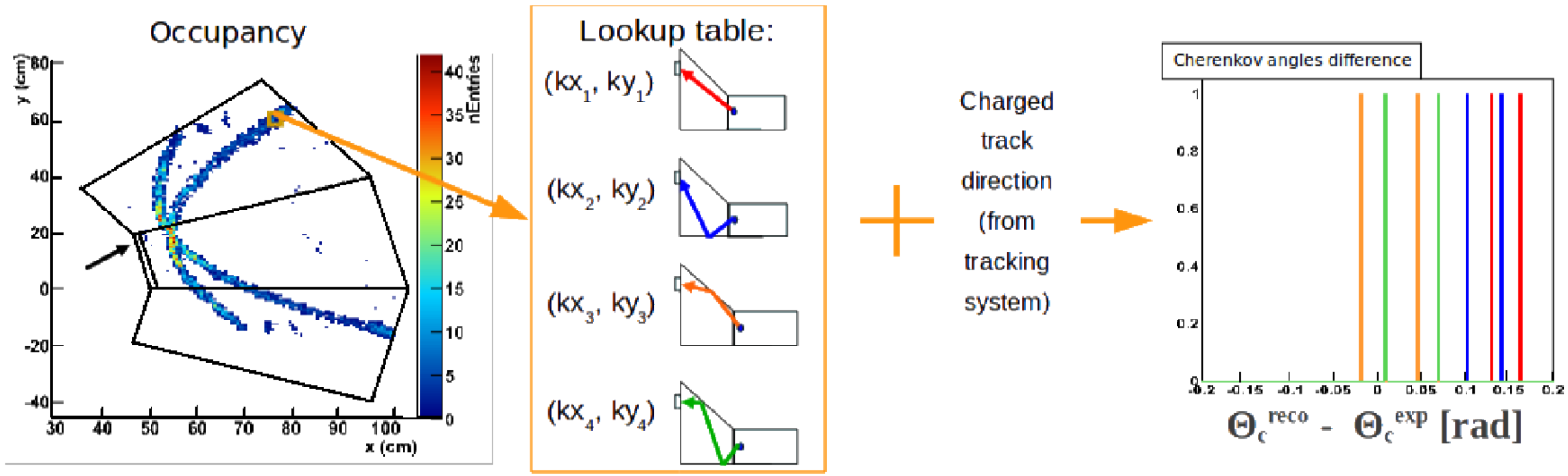
± 300 nsec trigger window (~500-1300 background hits/event)

± 8 nsec Δt window (1-2 background hits/sector/event)



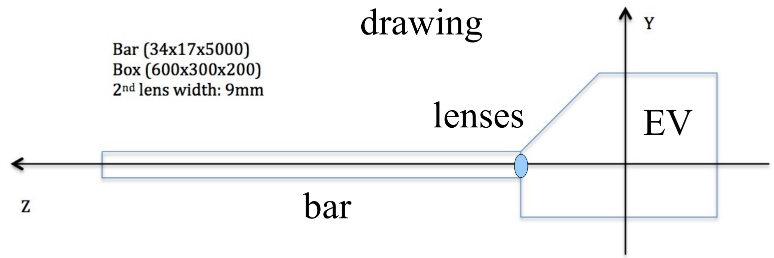


Event reconstruction II

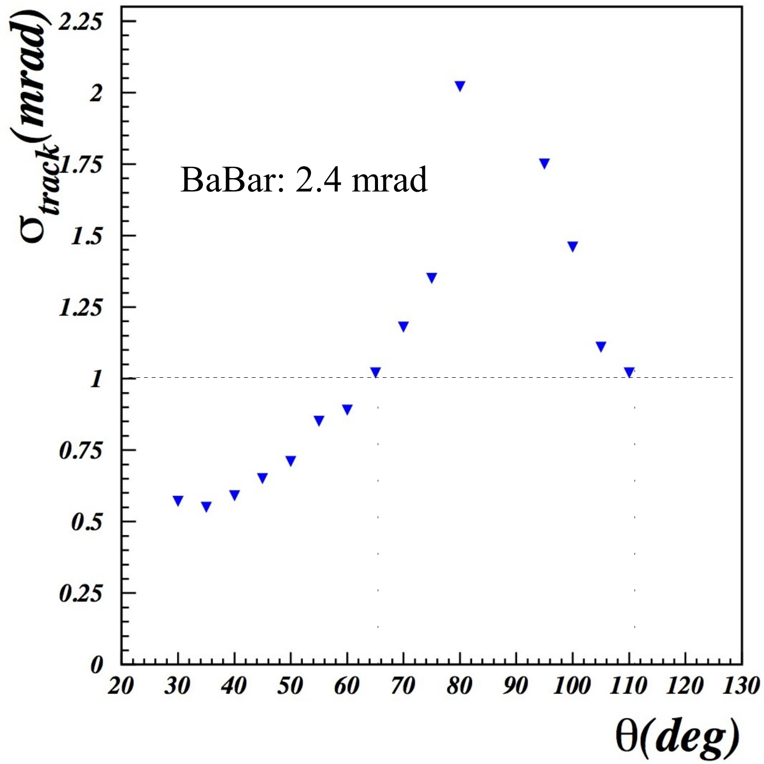


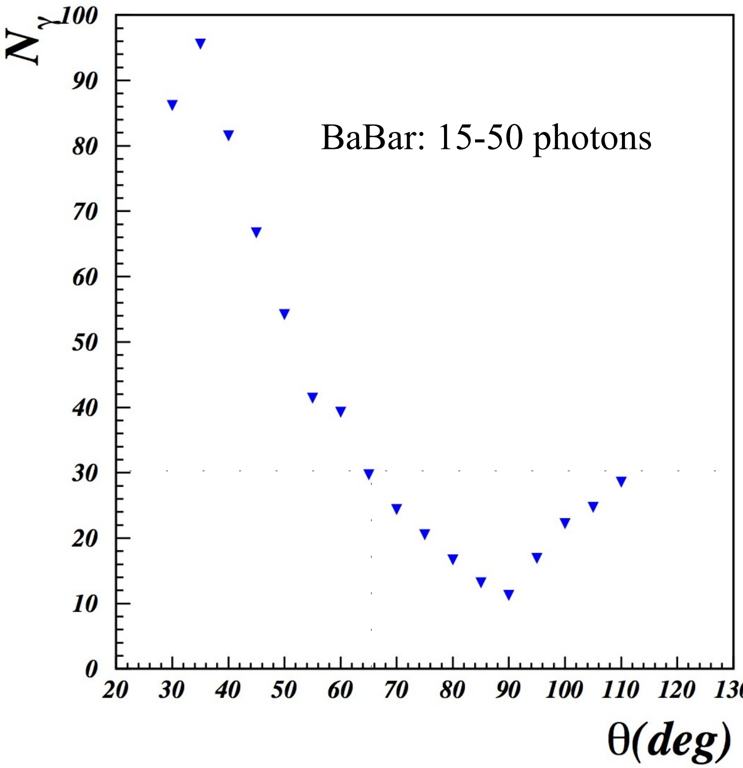
- For design purposes the main goal is to establish a figure of merit
- Explicitly reconstruct the single-photon θ_c resolution and photon yield
- Currently the algorithm uses a spatial lookup table (generated through simulation) combined with cuts on the time of propagation
  - Can be extended to include time explicitly in lookup table

Achieved θ_c resolution



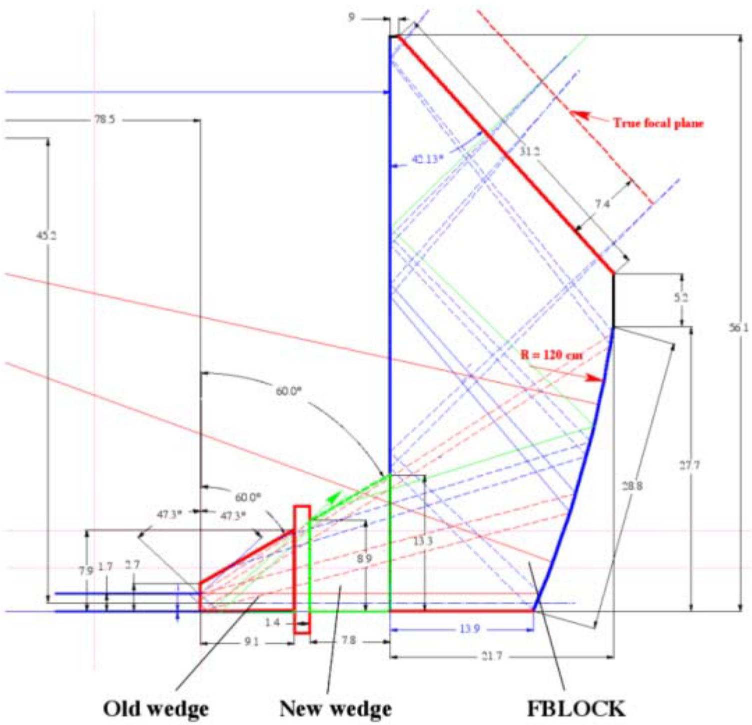
drcprop simulation with 2σ
cuts on time of propagation



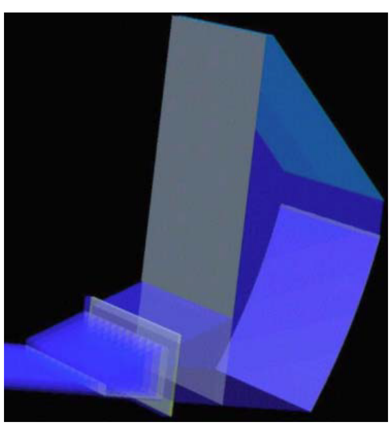


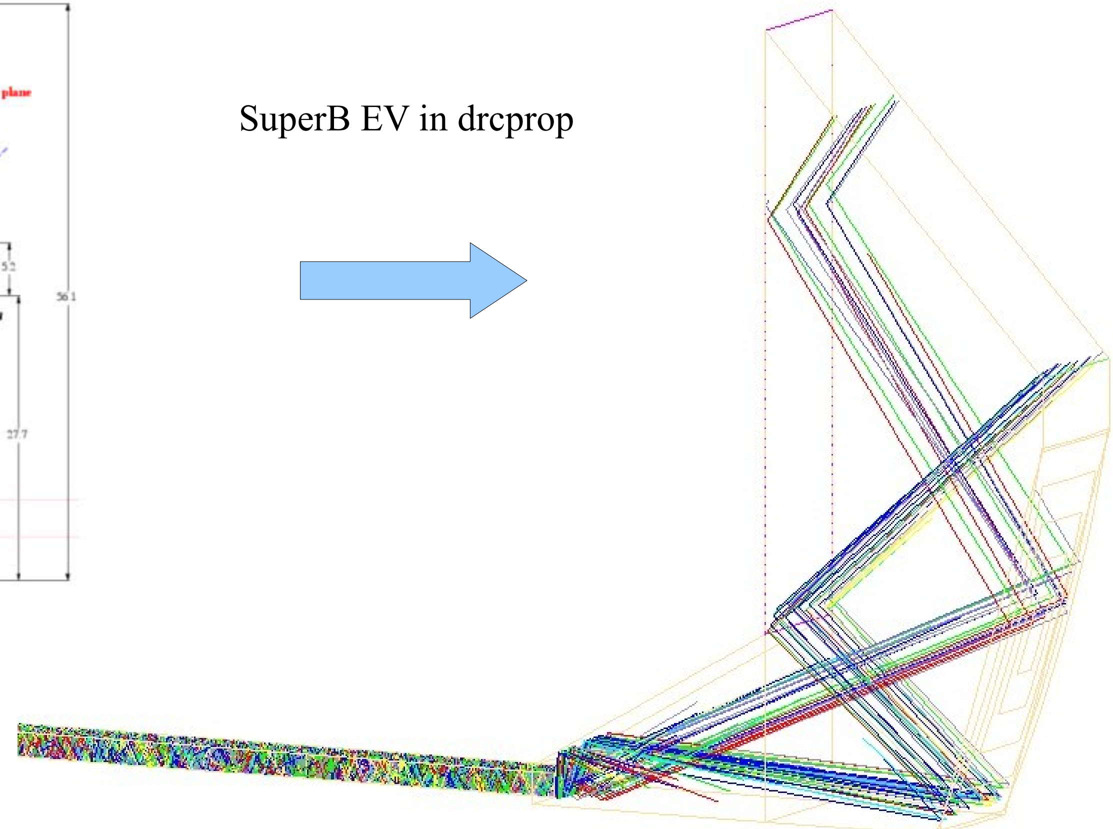
- Resolution per track includes focusing, pixel size, and chromaticity
- Resolution (σ) at forward angles is better than 1 mrad per track (*i.e.*, for all photons)
- New lens with high refractive index improves performance, especially around 90°

Focusing-mirror optics implemented in drcprop



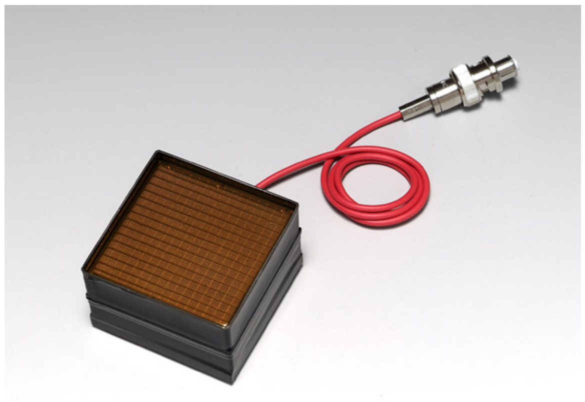
SuperB EV in drcprop



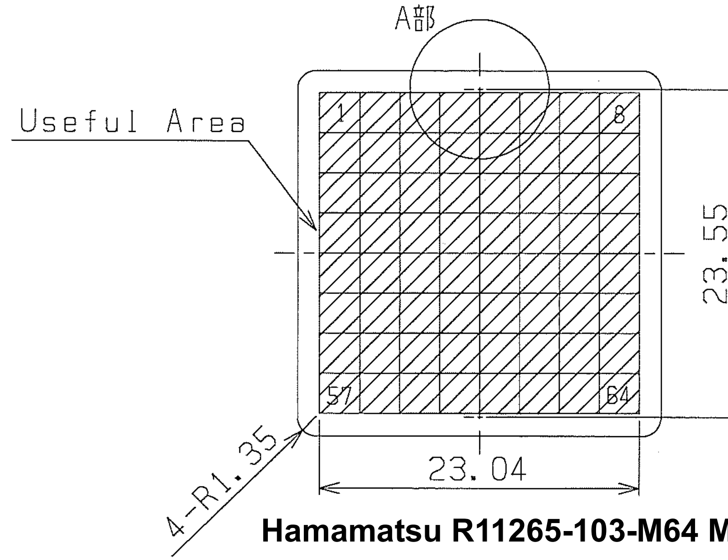


- SuperB mirror optics have been implemented in drcprop
- Will be modified to fit EIC requirements

Procurement of PMTs



Hamamatsu 9500 MaPMT
16x16 channels, $8.5k

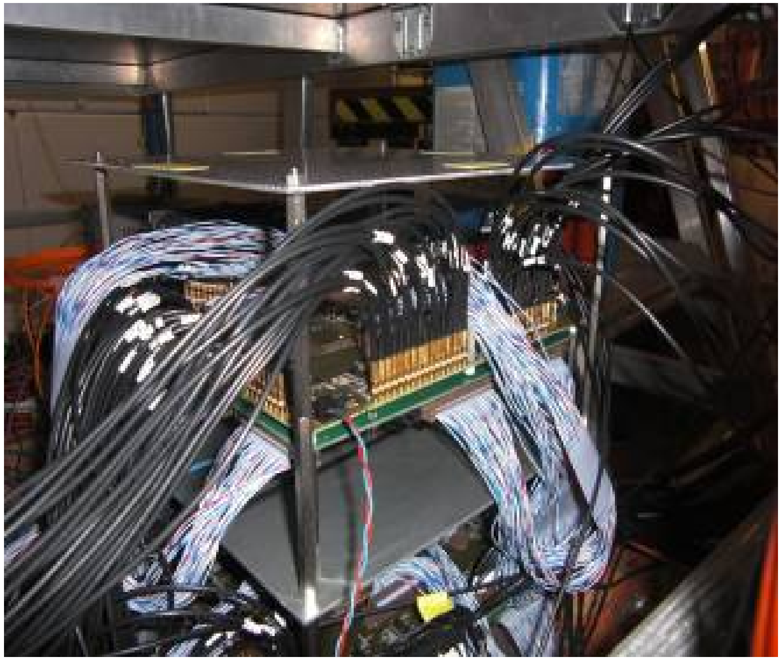


Hamamatsu R11265-103-M64 MaPMT

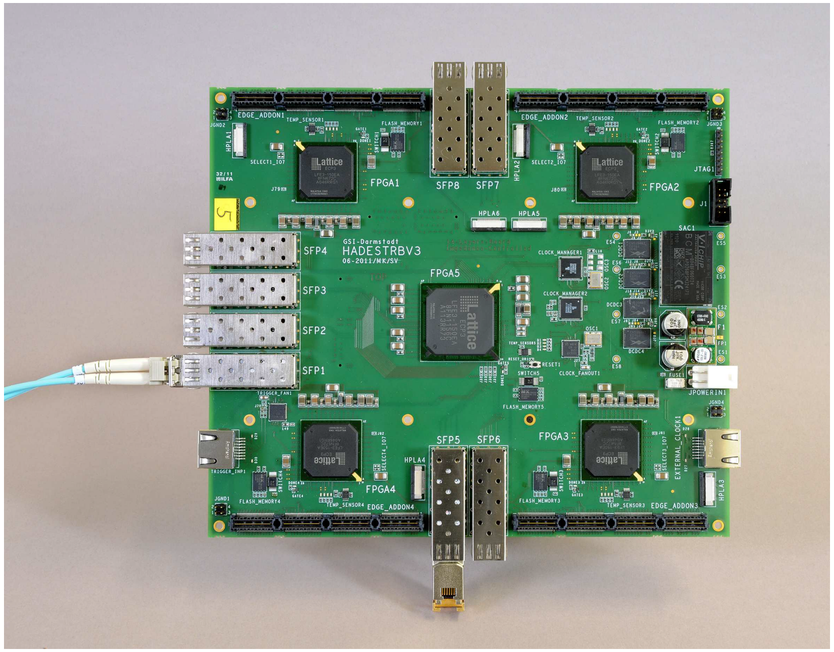
8x8 channels, $2.5k

- Procured four new, smaller Hamamatsu R11265 Multi-anode PMTs in lieu of one 9500
  - Delivered to JLab, awaiting DOE approval for shipment to GSI
  - Will be used for studies of focusing optics
- Delayed procurement of BINP round single-anode MCP-PMT for B-field studies
  - Currently not available with sufficiently good single-photon properties
  - Similar Photoek model is much more expensive (20k Euro)
  - Will postpone procurement until needed for tests at the new high-B field facility in year 2

Procurement of DAQ



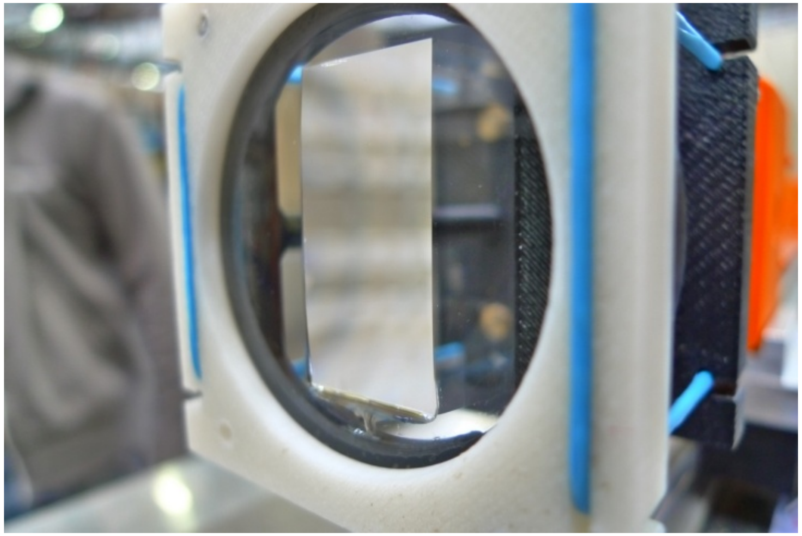
HADES TRBv2 readout system



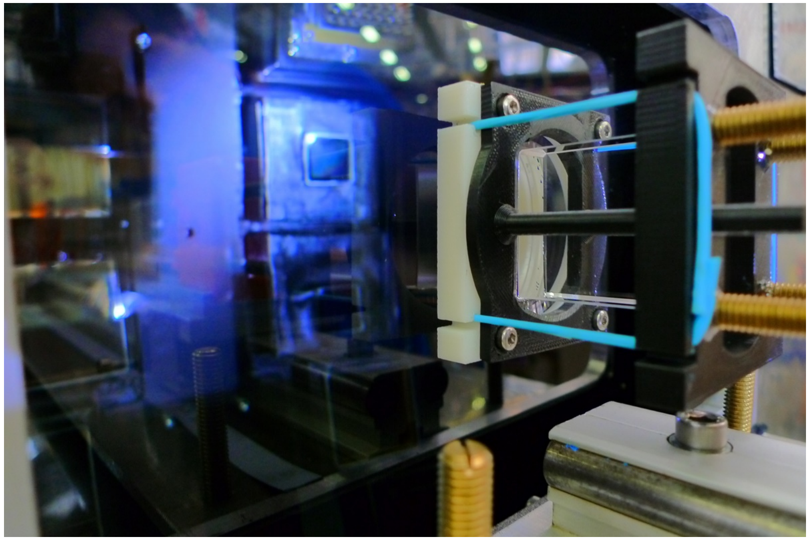
Procured TRBv3 board. Size is 20 x 23 cm.

- EIC setup will use the new HADES TRBv3
  - Better timing performance than predecessors
- New version can take full advantage of DAQ infrastructure used for PANDA DIRC
- Procurement of card complete, and interface to MaPMTs under way (awaiting their delivery)

PANDA: EV prototype tests at CERN

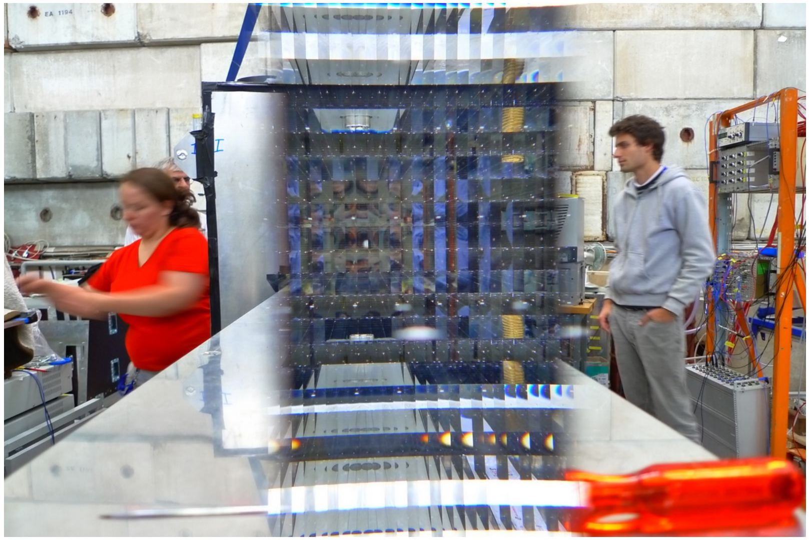


Simple plano-convex focusing lens attached to bar



Looking into mineral-oil filled EV; MCPs in black

- Tests carried out in 2011 and 2012
  - Pictures are from 2011 run
- 2012 test were very comprehensive
  - Data analysis in progress
  - Will guide EIC prototype design



Travel

Yearly collaboration meeting at JLab, March 23-29, 2012

- Full participation
- Was essential for laying out a detailed simulation strategy

Postdoc (H. Seraydaryan) visited GSI, May 20 – June 3, 2012

- Worked on event reconstruction, simulations, and familiarized herself with the hardware test setup at GSI

Detector R&D meeting at BNL, May 17-18, 2012

- The DIRC grant provided support for P. Nadel-Turonski for this meeting
- All other meetings at BNL during year 1 were covered by other JLab funds

What was achieved in year 1?

1. Major milestones

- Simulation results indicate that a θ_c resolution better than 1 mrad can be achieved
- A details simulation strategy is in place to optimize DIRC performace and integration
- Hardware procurement is well underway for sensor tests and later prototyping
- Travel funds have provided essential opportunities to meet and discuss in person

2. Year 1 deliverables as listed in proposal

1. Initial e/π identification requirements for the central EIC detector
2. Simulation and reconstruction framework for DIRC prototype
3. DIRC resolution studies and initial design of prototype
4. DAQ system tested using laser pulsed

- All goals have been achived in full, or in large part
- Initial work has been done on #1, but promising resultion results sugest that the momentum range may be larger than originally expected, so have to wait to assess final impact of DIRC
- Simulations give guidance on design of first prototype, but we would also want to fold in experience from the extensive PANDA test run at CERN in 2012
- DAQ system will be tested as soon as DOE review ends and PMTs can be sent from JLab

Year 1 spending summary

1. Hardware

- Budget: $41,970
- Completed procurements: $19,278
  - 4 MaPMTs @ $15,237
  - 1 TRBv3 DAQ card @ $4,041
- In progress: $18,192 budgeted
  - Shipping of MaPMTs to GSI: $232 budgeted
  - Cabling, etc for TRBv3: $6,600 budgeted
  - SiPM testing equipment: $11,360 budgeted
- Delayed: $4,500 budgeted
  - BINP 6 µm round single-anode MCP-PMT, not yet available: $3,000 budgeted
  - Computer for CUA undergrads will be purchased in the spring: $1,500 budgeted

2. Travel

- Budget: $11,400
- Spent: $11,368

3. Salaries

- Paid as planned

Approved funds

Budget	FY11	FY12	FY13	*Total*
Postdoc (50%)	$53,290	$54,000	$55,000	*$162,290*
Students	$8,300	$13,764	$13,764	*$35,828*
Hardware	$41,970	$58,630	$57,200	*$157,800*
Travel	$11,440	$13,606	$14,036	*$39,082*
Total	*$115,000*	*$140,000*	*$140,000*	*$395,000*

Matching funds are available for the ODU postdoc, H. Seratfaryan, hired in November 2011.
CUA undergrads work primarily in the summer quarter. All costs include overhead.

Budget	FY11	FY12	FY13	*Total*
Old Dominon Univesity (ODU)	$53,290	$54,000	$55,000	*$162,290*
Catholic University of America (CUA)	$9,800	$8,300	$8,300	*$26,400*
University of South Carolina (USC)		$7,606	$7,606	*$15,212*
JLab and GSI (through MoU)	$51,910	$70,094	$69,094	*$191,098*
Total	*$115,000*	*$140,000*	*$140,000*	*$140,000*

Deliverables for year 2 as outlined in proposal

1. Integration of DIRC into the EIC detector
2. Performance plots for EIC DIRC
3. Test of EV prototype
4. Evaluation of SiPM sensor response in magnetic fields up to 4.7 T
5. Cherenkov ring resolution in test beam (if available)

1. Experience from year 1

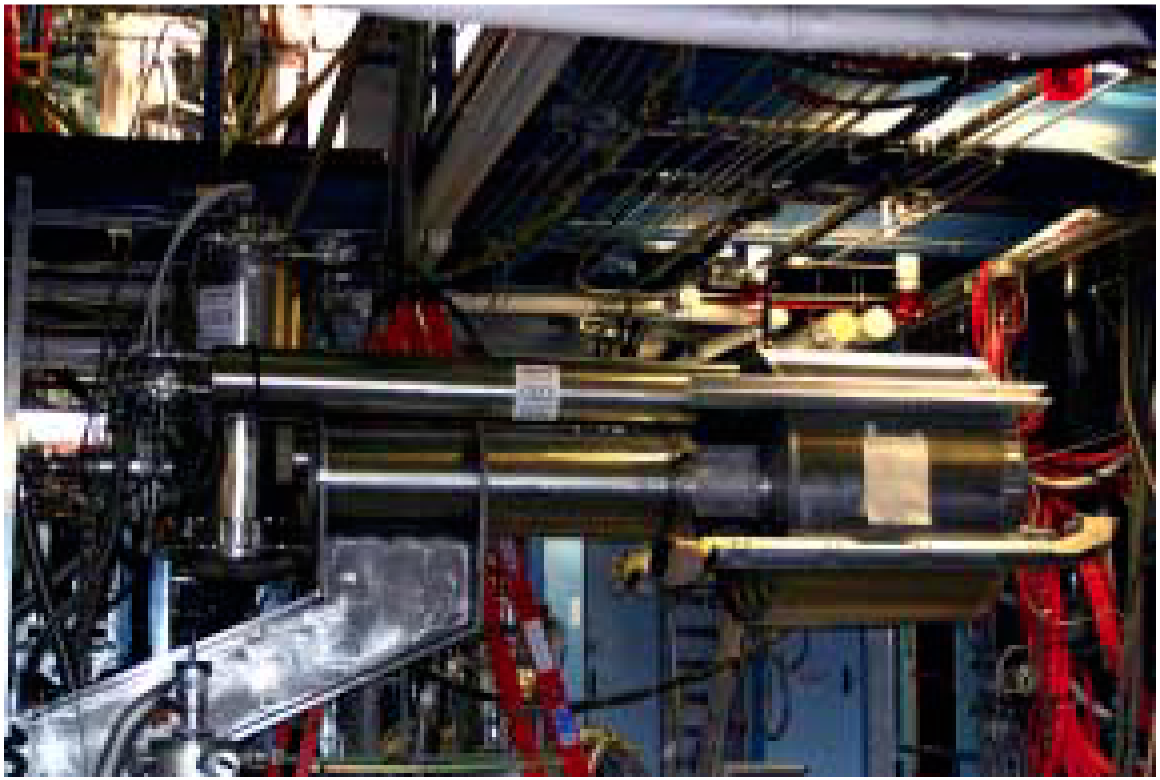
- First, lens-based prototype will be based on experience from year 1 simulations and PANDA test beam at CERN during 2012.

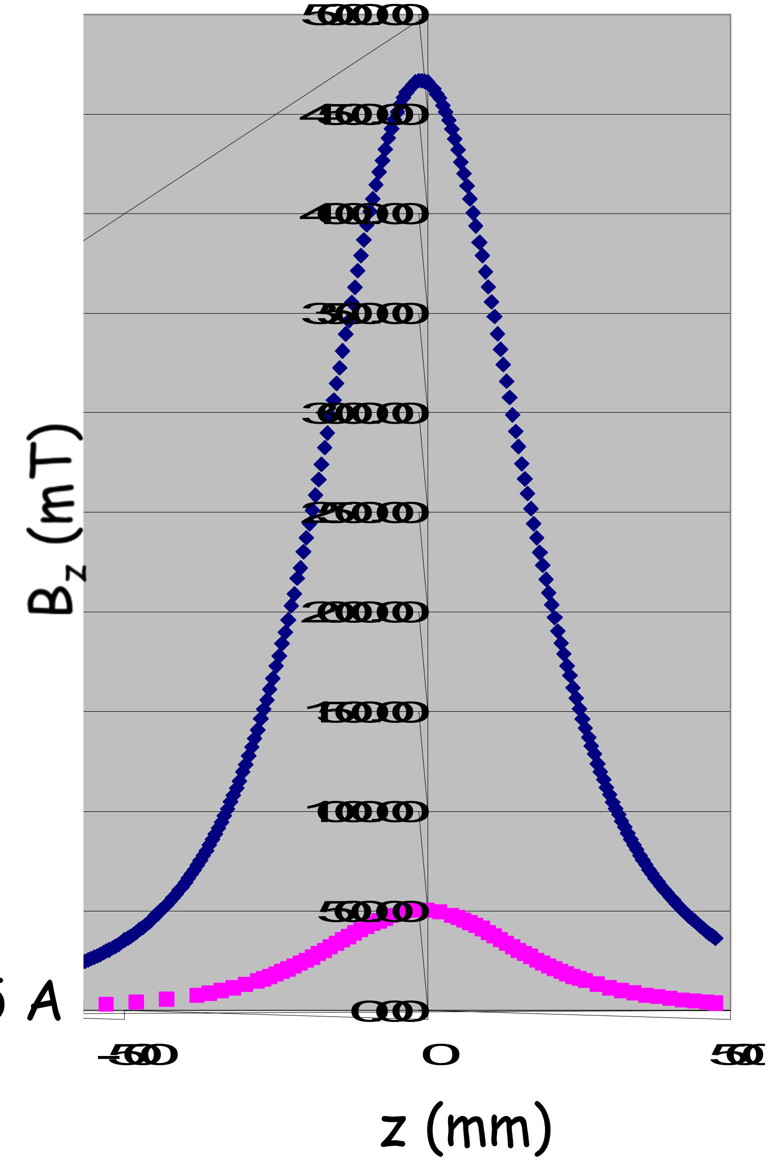
2. Simulations in year 2

- Simulations will continue for both the internal and external configurations during year 2, with the aim of developing a fully integrated solution.
- A techincal report will be prepared during the year to summarize our findings

3. New high-B field sensor test facility at JLab

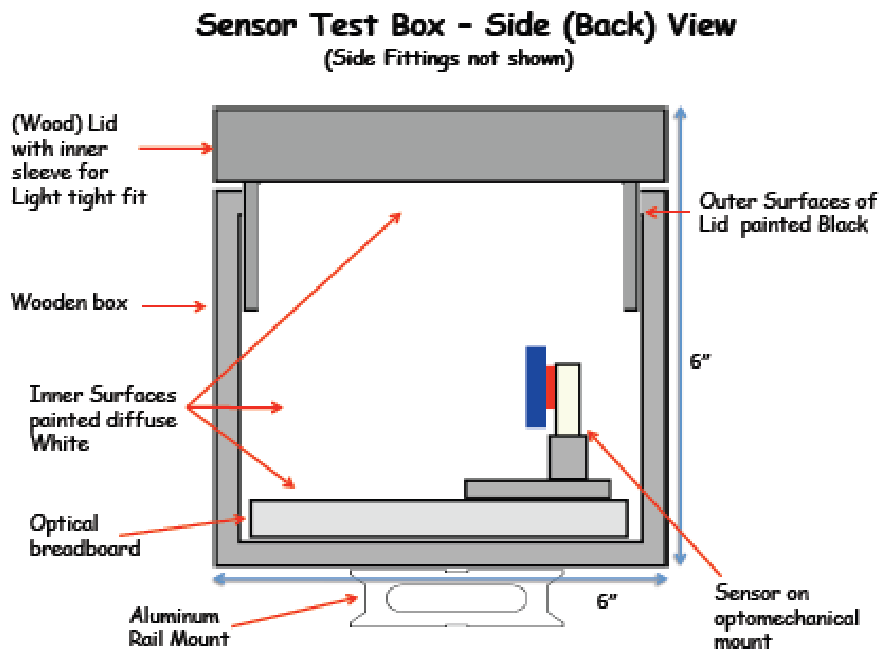
High-B sensor test facility – the magnet

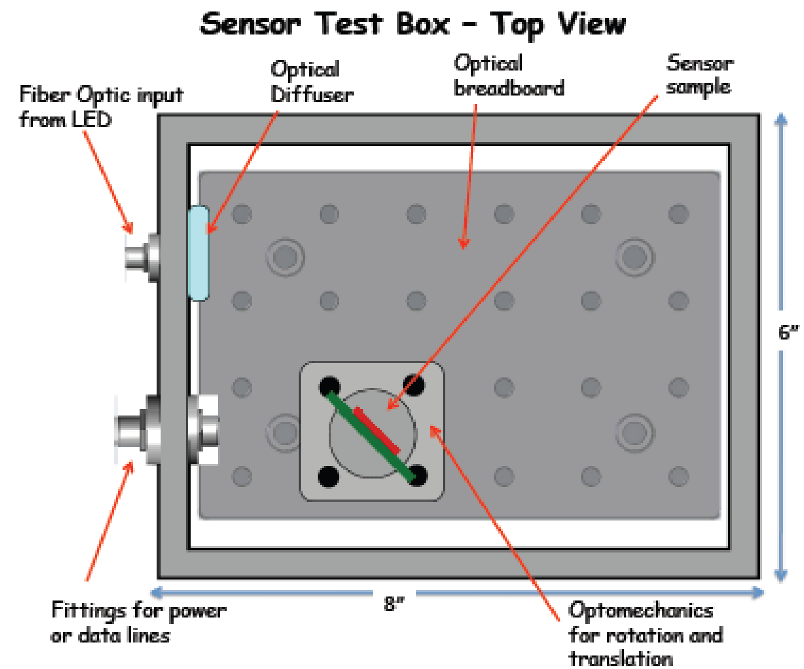




- Superconducting solenoid magnet
- Max. nominal field at center: 4.7 T at 535 A
- Adjustable nominal field
- Central hole diameter: 20 cm

High-B sensor test facility – the test box





Figures, courtesy of C. Zorn

- Box features
  - Light tight
  - Non-magnetic
  - Cool
  - Temperature controlled

- Suitable for testing
  - SiPMs
  - MCP-PMTs

High-B sensor test facility – timeline

1. Spring 2013

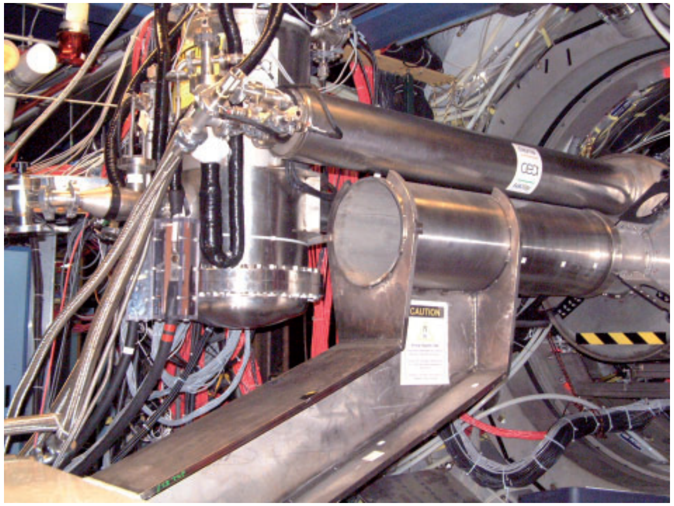
- Construction of test box
- Installation and setup in Laboratory

2. Summer 2013

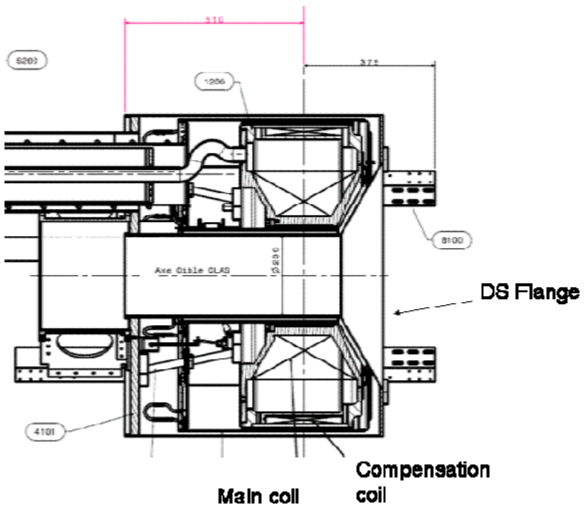
- SiPM magnetic field tolerance
  - Method, procedure, gain tolerance

3. Summer 2014

- MCP-PMT magnetic field tolerance
  - gain measurements



Magnet was used for DVCS in Hall B



Summary

Very promising results from ray-tracing simulations

- New lens design with high refractive index allows compact internal EV
- Proof of concept for high-performance DIRC
  - Resolutions better than 1 mrad obtained at forward angles
- Simulations of mirror-based optics with external EV will begin shortly

Hardware procurement on track

- Purchasing and shipping MaPMTs have taken longer than anticipated, but delays will not affect schedule
- 2012 PANDA test run at CERN will provide additional input for first prototype

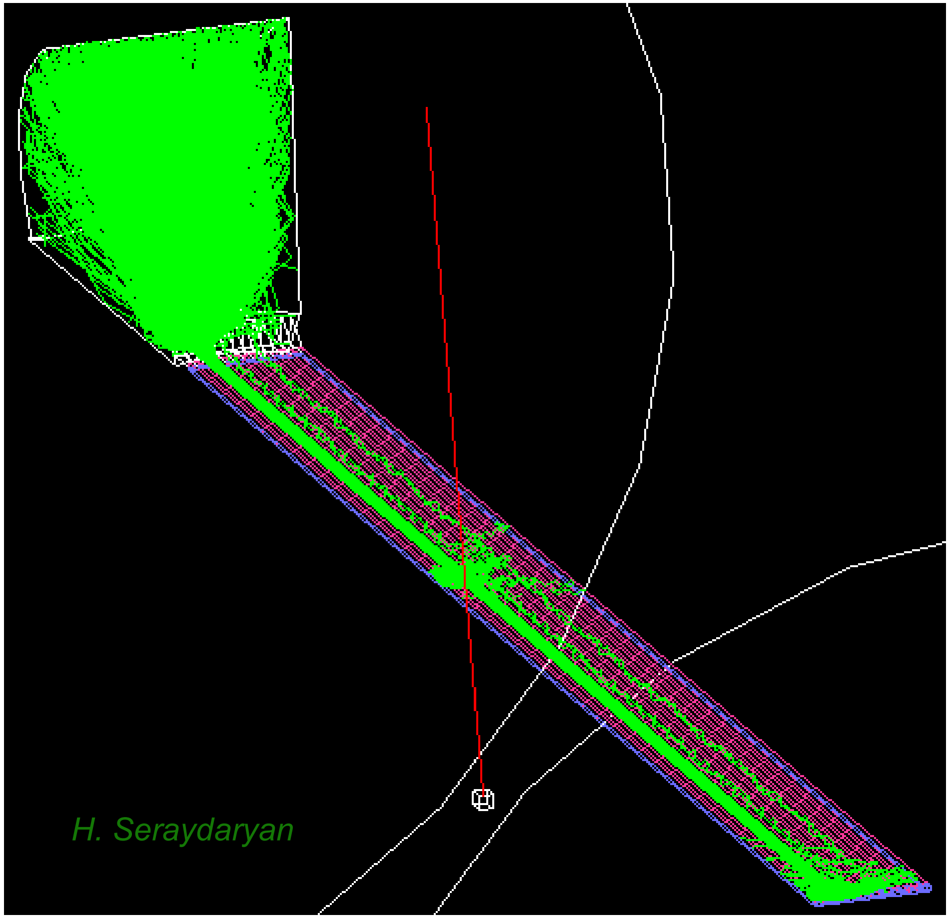
Travel funds have allowed a close collaboration to form

- We are looking forward to our next yearly collaboration meeting in 2013!

Backup

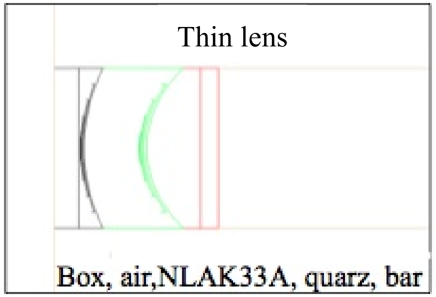
DIRC simulations and EV design

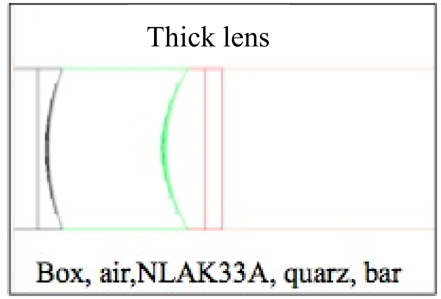
- Ray-tracing software (DRCPROP) will be used for parameter studies and the inititial design of the EV
- Detailed studies of the selected EV design will be performed using GEANT4
- This can then be implemented into the GEANT4 (GEMC) framework used for the EIC detector
  - Integration studies

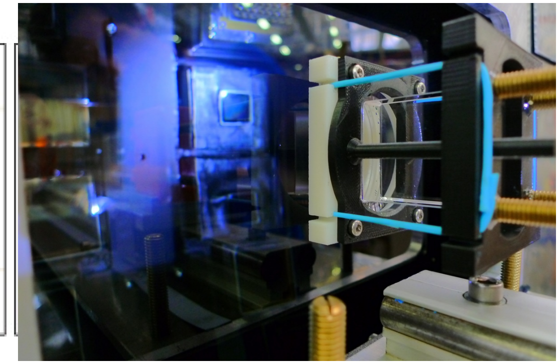


First tests of implementing a DIRC into GEANT4 at ODU/JLab using the BaBar geometry

Simulations using lenses with air gap



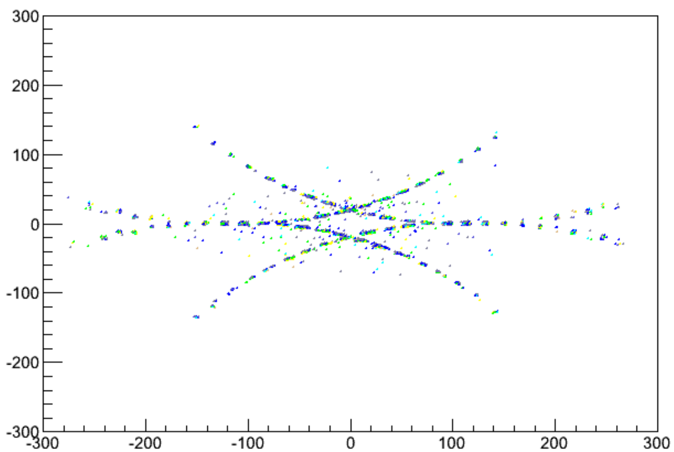




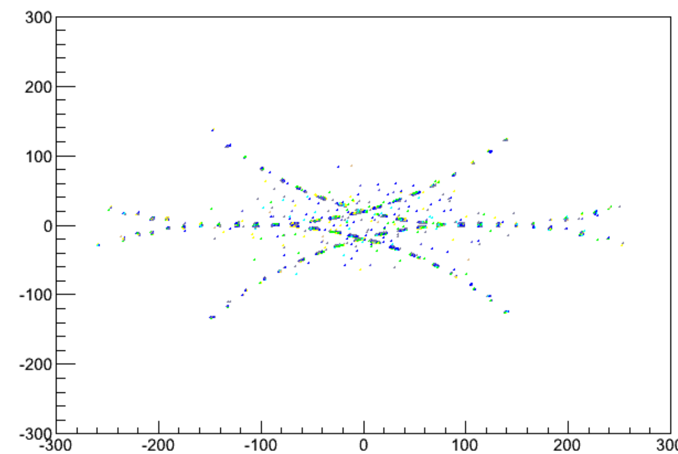
PANDA prototype with lens

$\beta = 0.99$, $\theta = 50°$, $\varphi = 70°$

Thin lens focussed



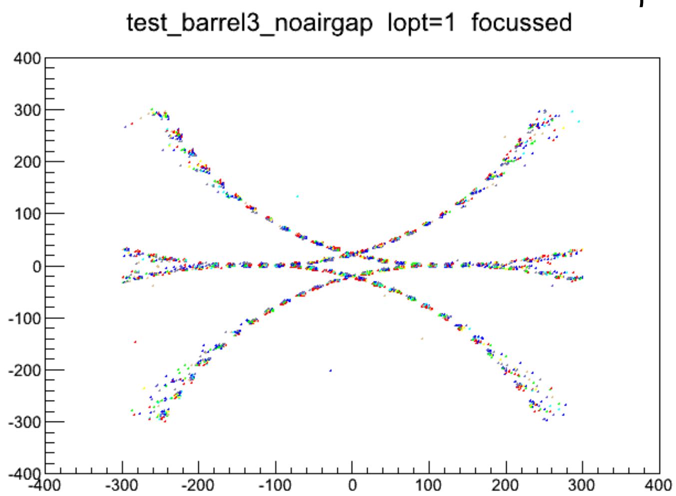
Thick lens focussed

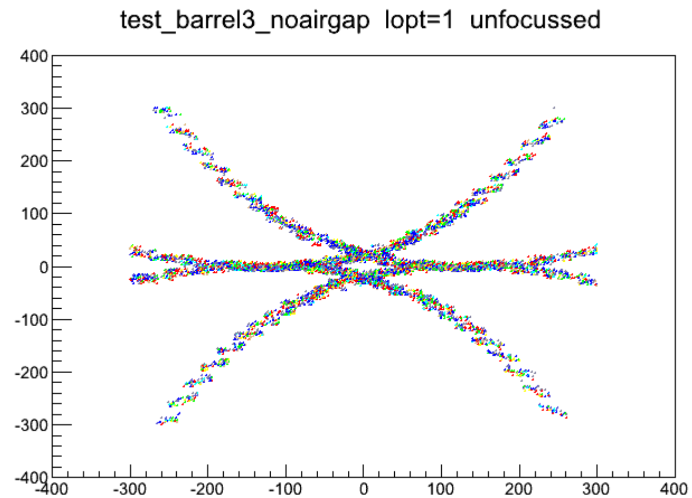


- Lenses with an air gap provide a sharp image
- Photon losses due to internal reflection for some track angles.

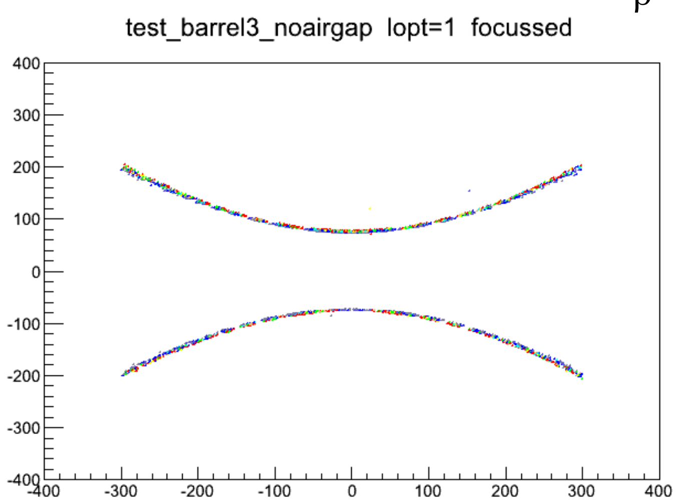
First simulations of new lens without air gap

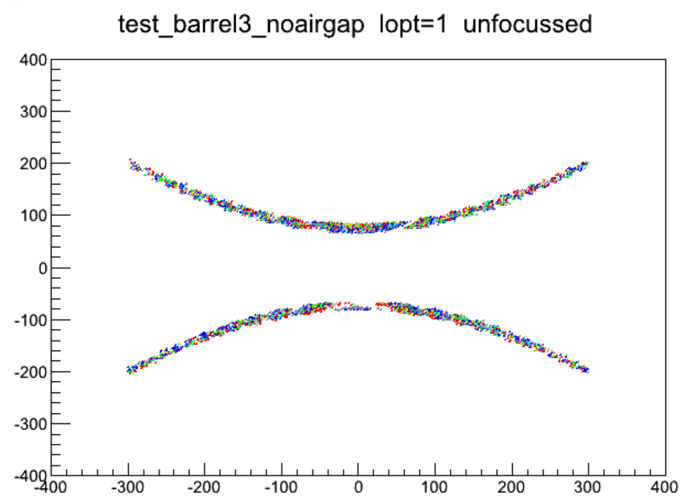
$\beta = 0.99$, $\theta = 50°$, $\varphi = 70°$





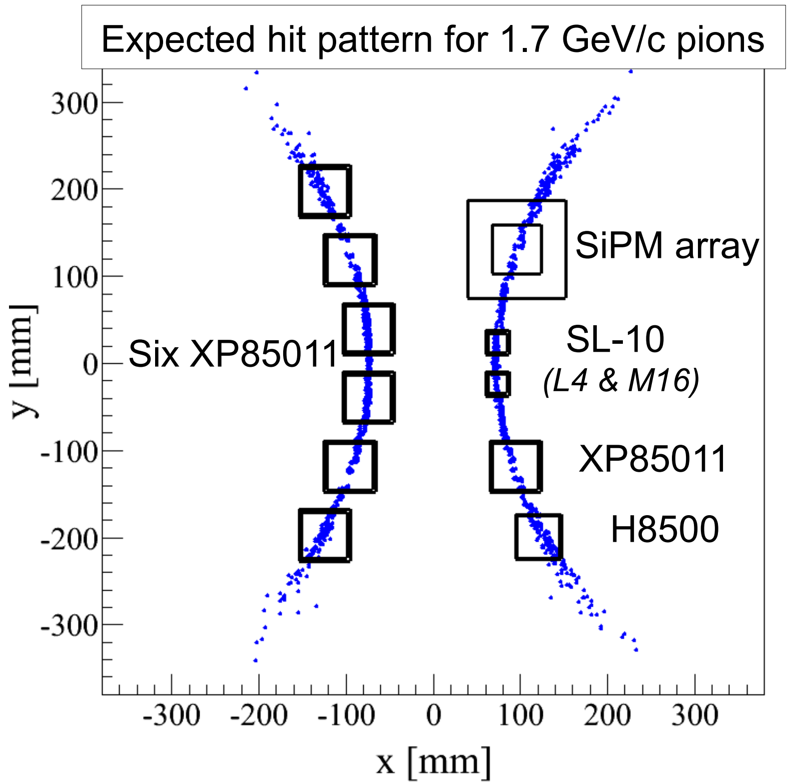
$\beta = 0.99$, $\theta = 60°$, $\varphi = 90°$



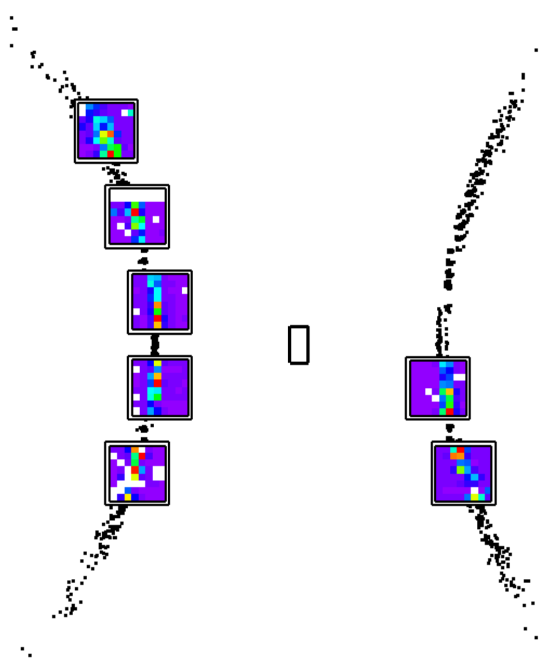


- High-n lenses and antireflective coatings can reduce photon losses

PANDA: results from 2011 tests at CERN



Simulation



Data

Supplementary threshold Cherenkov?